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Seismological constraints on ice properties at Dome C, Antarctica, from H/V measurements

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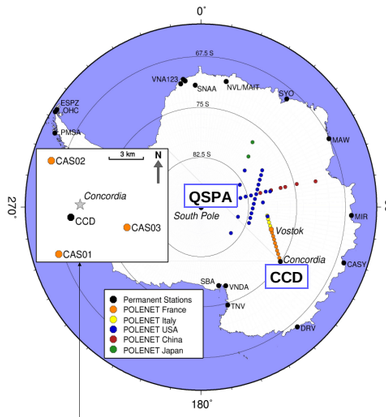
Summary

The French-Italian Concordia (CCD) seismological station at **Dome C** is one of only two observatories installed on the ice cap inside the Antarctic continent. We have analyzed the **seismic signal due to the ambient noise** at this station, and at 3 temporary stations 5 km from Concordia, in order to **determine the ice properties** beneath these stations.

We have applied a method based on the **horizontal to vertical (H/V) spectral ratio**, commonly used to analyze soil response for seismic risk evaluation. It reveals a main resonance peak in the spectral ratios at frequencies between 6.7 Hz and 8 Hz, ascribable to the uppermost ice sheet.

The resonance frequency is well explained by a **30 meter thick unconsolidated snow or firn layer** with a low S-velocity of 0.9 km/s, overlying a consolidated layer with S-velocity 2.0 km/s. This sharp velocity contrast is not related to a density contrast. We suggest that it is due to the **closure of a large number of bubbles** at about 30m depth.

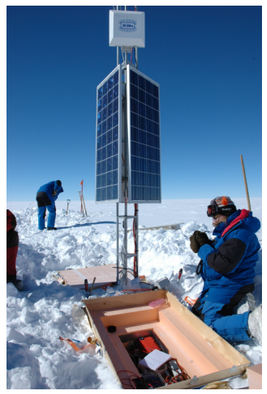


Only two permanent broadband seismic stations are located on the ice cap inside the Antarctic continent:

CCD (Italian-French)
Ice thickness = 3270 m
Depth below surface: 12m

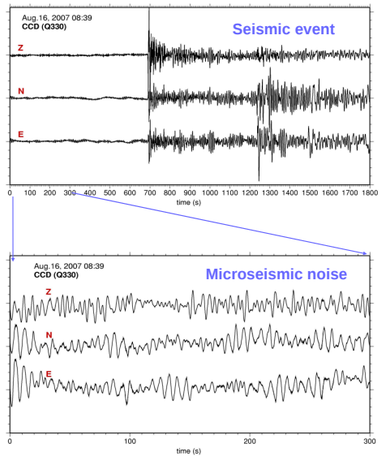
QSPA (USA)
Ice thickness ~ 2500 m
Depth below surface: 275m

CAS01, CAS02, CAS03
are 3 autonomous broadband stations set up about 5 km away from CCD during the summer 2007-2008.
Depth below surface: 1m.



Setup of the autonomous broadband seismological station CAS03

Seismic records

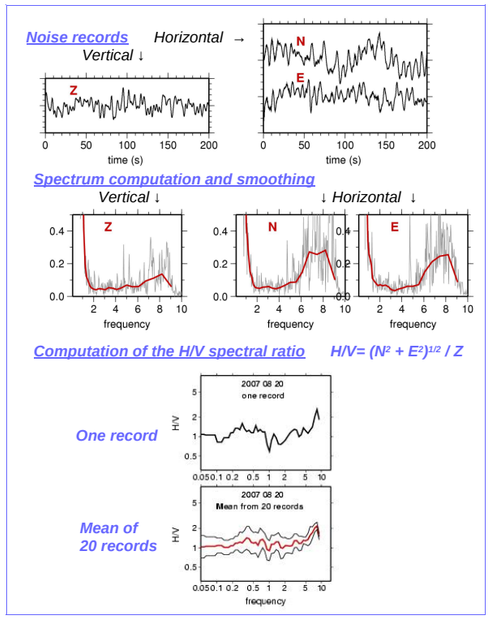


The motion is recorded in **3 directions** (one vertical and two horizontal) with broadband seismometers in the frequency range 5.10^{-3} Hz - 40 Hz.
The sampling rate is 0.05 s.

Seismic noise is a permanent motion of the Earth. It includes:

- Microseisms primarily due to the interaction of oceans with solid Earth, with periods T= 4-10s. They are mostly Rayleigh waves.
- High frequency noise (T< 1s) due to anthropic activity. It includes body waves (P and S waves) and surface waves (Rayleigh and Love waves).

The H/V method



The H/V method makes use of the behavior of the waves generated at interfaces with strong impedance contrasts.

Rock site conditions: For a station installed on rock with little topography: **H/V ~1**

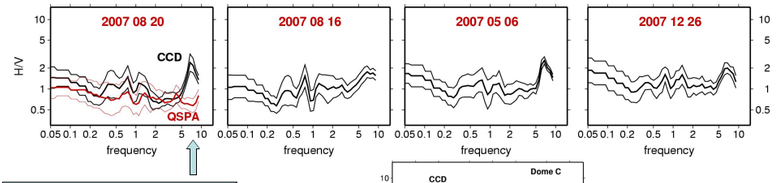
Sedimentary layer over a rocky half space: Resonance peak with fundamental frequency **$f : v_S/4h$** where v_s is the S-velocity in the layer and h the layer thickness

More complex situations produce multiple resonance peaks in the spectral ratios:

- Presence of multiple layers
- Weak impedance contrasts
- Non-flat layers
- Surface topography

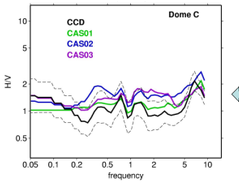
H/V at Dome C

At station CCD:
The most prominent feature is a **peak at 6.7 Hz**. Secondary peaks are observed at 0.40, 0.75 and 1.30 Hz
A small time variability in the spectra is due to a change in the composition of the noise depending on the day.



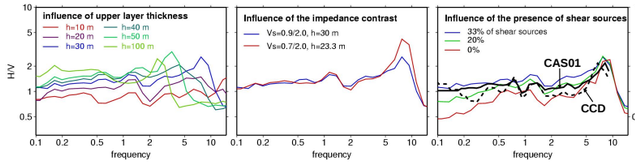
The **peak at 6.7 Hz** is not observed at the burried station QSPA.
It is likely to be due to the **uppermost ice sheet**

At all the Dome C stations



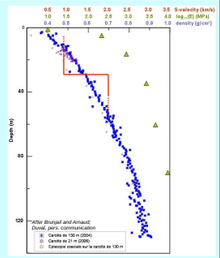
A small geographic variability is observed: The main peak is at 8 Hz at the temporary stations, denoting slight variations in the ice sheet.

Modelling with synthetic seismograms



Synthetic noise is generated by summing a large number of synthetic seismograms with random properties.
Important parameters are:
-The thickness of the upper layer
- the impedance contrast
- the composition of the noise

Results and perspectives



From synthetic seismograms, we infer:
The **thickness** of the upper layer: **h=30 m**
The **impedance contrast** at the base of this layer: **v_{S1} = 0.9 km/s v_{S2}=2.0 km/s**
The **composition of the noise :** 20 to 30% of **shear sources at low frequency,** probably due to the wind-surface interaction.
Subglacial lakes are not detectable with this method.

The low S-velocity layer of 30 m thickness at the top of the ice sheet is interpreted as a **soft, firn or snow layer overlying consolidated ice**. The discontinuity at the base of the soft layer is not observed on density or Young modulus and does not coincide with a dielectrical discontinuity. The great sensitivity of S-waves to fluid or gaz inclusions suggests that it it is due to the **closure of pores at about 30m below surface.**

The **H/V method appears as a valuable tool** to investigate the seismic properties of the ice sheet. However, the present study suffers from the low sampling rate, which limits the investigation at high frequency.
A better knowledge of the seismic properties of the ice sheet is necessary to correct the effect of ice on the waveforms of the seismic records for other uses (e.g. determination of focal solutions, tomography, etc…). Specific experiments may be planed for this purpose.